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Universal experimental test for the role of free charge carriers in the thermal Casimir effect within a micrometer separation range

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Abstract

© 2017 American Physical Society. We propose a universal experiment to measure the differential Casimir force between a Au-coated sphere and two halves of a structured plate covered with a P-doped Si overlayer. The concentration of free charge carriers in the overlayer is chosen slightly below the critical one, for which the phase transition from dielectric to metal occurs. One half of the structured plate is insulating, while the second half is made of gold. For the former we consider two structures, one consisting of bulk high-resistivity Si and the other of a layer of SiO2 followed by bulk high-resistivity Si. The differential Casimir force is computed within the Lifshitz theory using four approaches that have been proposed in the literature to account for the role of free charge carriers in metallic and dielectric materials interacting with quantum fluctuations. According to these approaches, Au at low frequencies is described by either the Drude or the plasma model, whereas the free charge carriers in dielectric materials at room temperature are either taken into account or disregarded. It is shown that the values of differential Casimir forces, computed in the micrometer separation range using these four approaches, are widely distinct from each other and can be easily discriminated experimentally. It is shown that for all approaches the thermal component of the differential Casimir force is sufficiently large for direct observation. The possible errors and uncertainties in the proposed experiment are estimated and its importance for the theory of quantum fluctuations is discussed.

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References

[1] H. B. G. Casimir, Proc. Kon. Ned. Akad. Wet. B 51, 793 (1948).

[2] M. Bordag, G. L. Klimchitskaya, U. Mohideen, and V. M. Mostepanenko, Advances in the Casimir Effect (Oxford University Press, Oxford, UK, 2015).

[3] G. L. Klimchitskaya, U. Mohideen, and V. M. Mostepanenko, Rev. Mod. Phys. 81, 1827 (2009). RMPHAT 0034-6861 10.1103/RevModPhys.81.1827

[4] A. W. Rodrigues, F. Capasso, and S. G. Johnson, Nature Photon. 5, 211 (2011). 1749-4885 10.1038/nphoton.2011.39

[5] L. M. Woods, D. A. R. Dalvit, A. Tkatchenko, P. Rodrigues-Lopez, A. W. Rodrigues, and R. Podgornik, Rev. Mod. Phys. 88, 045003 (2016). RMPHAT 0034-6861 10.1103/RevModPhys.88.045003

[6] V. A. Parsegian, Van der Waals Forces: A Handbook for Biologists, Chemists, Engineers, and Physicists (Cambridge University Press, Cambridge, UK, 2005).

[7] E. M. Lifshitz, Zh. Eksp. Teor. Fiz. 29, 94 (1955)

[8] E. M. Lifshitz, [Sov. Phys. JETP 2, 73 (1956)].

[9] M. Boström and Bo E. Sernelius, Phys. Rev. Lett. 84, 4757 (2000). PRLTAO 0031-9007 10.1103/PhysRevLett.84.4757

[10] M. Bordag, B. Geyer, G. L. Klimchitskaya, and V. M. Mostepanenko, Phys. Rev. Lett. 85, 503 (2000). PRLTAO 0031-9007 10.1103/PhysRevLett.85.503

[11] V. B. Bezerra, G. L. Klimchitskaya, and V. M. Mostepanenko, Phys. Rev. A 65, 052113 (2002). PLRAAN 1050-2947 10.1103/PhysRevA.65.052113

[12] V. B. Bezerra, G. L. Klimchitskaya, and V. M. Mostepanenko, Phys. Rev. A 66, 062112 (2002). PLRAAN 1050-2947 10.1103/PhysRevA.66.062112

[13] V. B. Bezerra, G. L. Klimchitskaya, V. M. Mostepanenko, and C. Romero, Phys. Rev. A 69, 022119 (2004). PLRAAN 1050-2947 10.1103/PhysRevA.69.022119

[14] M. Bordag and I. G. Pirozhenko, Phys. Rev. D 82, 125016 (2010). PRVDAQ 1550-7998 10.1103/PhysRevD.82.125016

[15] G. L. Klimchitskaya and C. C. Korikov, Phys. Rev. A 91, 032119 (2015) PLRAAN 1050-2947 10.1103/PhysRevA.91.032119;

[16] G. L. Klimchitskaya and C. C. Korikov, Phys. Rev. A 92, 029902 (E) (2015). PLRAAN 1050-2947 10.1103/PhysRevA.92.029902

[17] P. R. Buenzli and P. A. Martin, Phys. Rev. E 77, 011114 (2008). PLEEE8 1539-3755 10.1103/PhysRevE.77.011114

[18] G. Bimonte, Phys. Rev. A 79, 042107 (2009). PLRAAN 1050-2947 10.1103/PhysRevA.79.042107

[19] G. Bimonte, New J. Phys. 9, 281 (2007). NJOPFM 1367-2630 10.1088/1367-2630/9/8/281

[20] F. Intravaia and C. Henkel, Phys. Rev. Lett. 103, 130405 (2009). PRLTAO 0031-9007 10.1103/PhysRevLett.103.130405

[21] F. Intravaia, S. A. Ellingsen, and C. Henkel, Phys. Rev. A 82, 032504 (2010). PLRAAN 1050-2947 10.1103/PhysRevA.82.032504

[22] R. S. Decca, E. Fischbach, G. L. Klimchitskaya, D. E. Krause, D. López, and V. M. Mostepanenko, Phys. Rev. D 68, 116003 (2003). 0556-2821 10.1103/PhysRevD.68.116003

[23] R. S. Decca, D. López, E. Fischbach, G. L. Klimchitskaya, D. E. Krause, and V. M. Mostepanenko, Ann. Phys. (NY) 318, 37 (2005). APNYA6 0003-4916 10.1016/j.aop.2005.03.007

[24] R. S. Decca, D. López, E. Fischbach, G. L. Klimchitskaya, D. E. Krause, and V. M. Mostepanenko, Phys. Rev. D 75, 077101 (2007). PRVDAQ 1550-7998 10.1103/PhysRevD.75.077101

[25] R. S. Decca, D. López, E. Fischbach, G. L. Klimchitskaya, D. E. Krause, and V. M. Mostepanenko, Eur. Phys. J. C 51, 963 (2007). EPCFFB 1434-6044 10.1140/epjc/s10052-007-0346-z

[26] C.-C. Chang, A. A. Banishev, R. Castillo-Garza, G. L. Klimchitskaya, V. M. Mostepanenko, and U. Mohideen, Phys. Rev. B 85, 165443 (2012). PRBMDO 1098-0121 10.1103/PhysRevB.85.165443

[27] A. A. Banishev, G. L. Klimchitskaya, V. M. Mostepanenko, and U. Mohideen, Phys. Rev. Lett. 110, 137401 (2013). PRLTAO 0031-9007 10.1103/PhysRevLett.110.137401

[28] A. A. Banishev, G. L. Klimchitskaya, V. M. Mostepanenko, and U. Mohideen, Phys. Rev. B 88, 155410 (2013). PRBMDO 1098-0121 10.1103/PhysRevB.88.155410

[29] V. M. Mostepanenko, J. Phys. Condens. Matter 27, 214013 (2015). JCOMEL 0953-8984 10.1088/0953-8984/27/21/214013

[30] A. O. Sushkov, W. J. Kim, D. A. R. Dalvit, and S. K. Lamoreaux, Nat. Phys. 7, 230 (2011). 1745-2473 10.1038/nphys1909

[31] V. B. Bezerra, G. L. Klimchitskaya, U. Mohideen, V. M. Mostepanenko, and C. Romero, Phys. Rev. B 83, 075417 (2011). PRBMDO 1098-0121 10.1103/PhysRevB.83.075417

[32] G. L. Klimchitskaya, M. Bordag, E. Fischbach, D. E. Krause, and V. M. Mostepanenko, Int. J. Mod. Phys. A 26, 3918 (2011). IMPAEF 0217-751X 10.1142/S0217751X11054371

[33] J. M. Obrecht, R. J. Wild, M. Antezza, L. P. Pitaevskii, S. Stringari, and E. A. Cornell, Phys. Rev. Lett. 98, 063201 (2007). PRLTAO 0031-9007 10.1103/PhysRevLett.98.063201

[34] F. Chen, G. L. Klimchitskaya, V. M. Mostepanenko, and U. Mohideen, Phys. Rev. B 76, 035338 (2007). PRBMDO 1098-0121 10.1103/PhysRevB.76.035338

[35] C.-C. Chang, A. A. Banishev, G. L. Klimchitskaya, V. M. Mostepanenko, and U. Mohideen, Phys. Rev. Lett. 107, 090403 (2011). PRLTAO 0031-9007 10.1103/PhysRevLett.107.090403

[36] A. A. Banishev, C.-C. Chang, R. Castillo-Garza, G. L. Klimchitskaya, V. M. Mostepanenko, and U. Mohideen, Phys. Rev. B 85, 045436 (2012). PRBMDO 1098-0121 10.1103/PhysRevB.85.045436

[37] G. L. Klimchitskaya and V. M. Mostepanenko, J. Phys. A 41, 312002 (2008). 1751-8113 10.1088/1751-8113/41/31/312002

[38] B. Geyer, G. L. Klimchitskaya, and V. M. Mostepanenko, Phys. Rev. D 72, 085009 (2005). PRVDAQ 1550-7998 10.1103/PhysRevD.72.085009

[39] G. L. Klimchitskaya, U. Mohideen, and V. M. Mostepanenko, J. Phys. A 41, 432001 (2008). 1751-8113 10.1088/1751-8113/41/43/432001

[40] B. Geyer, G. L. Klimchitskaya, and V. M. Mostepanenko, Ann. Phys. (NY) 323, 291 (2008). APNYA6 0003-4916 10.1016/j.aop.2007.04.005

[41] G. L. Klimchitskaya and C. C. Korikov, J. Phys. Condens. Matter 27, 214007 (2015). JCOMEL 0953-8984 10.1088/0953-8984/27/21/214007

[42] R. O. Behunin, D. A. R. Dalvit, R. S. Decca, C. Genet, I. W. Jung, A. Lambrecht, A. Liscio, D. López, S. Reynaud, G. Schnoering, G. Voisin, and Y. Zeng, Phys. Rev. A 90, 062115 (2014). PLRAAN 1050-2947 10.1103/PhysRevA.90.062115

[43] P. J. van Zwol, G. Palasantzas, and J. Th. M. De Hosson, Phys. Rev. B 77, 075412 (2008). PRBMDO 1098-0121 10.1103/PhysRevB.77.075412

[44] G. Bimonte, Phys. Rev. Lett. 112, 240401 (2014). PRLTAO 0031-9007 10.1103/PhysRevLett.112.240401

[45] G. Bimonte, D. López, and R. S. Decca, Phys. Rev. B 93, 184434 (2016). 2469-9950 10.1103/PhysRevB.93.184434

[46] R. S. Decca, D. López, H. B. Chan, E. Fischbach, D. E. Krause, and C. R. Jamell, Phys. Rev. Lett. 94, 240401 (2005). PRLTAO 0031-9007 10.1103/PhysRevLett.94.240401

[47] Y.-J. Chen, W. K. Tham, D. E. Krause, D. López, E. Fischbach, and R. S. Decca, Phys. Rev. Lett. 116, 221102 (2016). PRLTAO 0031-9007 10.1103/PhysRevLett.116.221102

[48] G. L. Klimchitskaya and V. M. Mostepanenko, Phys. Rev. A 92, 042109 (2015). PLRAAN 1050-2947 10.1103/PhysRevA.92.042109

[49] G. L. Klimchitskaya and V. M. Mostepanenko, Phys. Rev. A 93, 042508 (2016). 2469-9926 10.1103/PhysRevA.93.042508

[50] G. L. Klimchitskaya and V. M. Mostepanenko, Phys. Rev. B 94, 045404 (2016). 2469-9950 10.1103/PhysRevB.94.045404

[51] G. L. Klimchitskaya and V. M. Mostepanenko, Phys. Rev. A 95, 012130 (2017). 2469-9926 10.1103/PhysRevA.95.012130

[52] G. Bimonte, Phys. Rev. Lett. 113, 240405 (2014). PRLTAO 0031-9007 10.1103/PhysRevLett.113.240405

[53] G. Bimonte, Phys. Rev. B 91, 205443 (2015). PRBMDO 1098-0121 10.1103/PhysRevB.91.205443

[54] T. F. Rosenbaum, R. F. Milligan, M. A. Paalanen, G. A. Thomas, R. N. Bhatt, and W. Lin, Phys. Rev. B 27, 7509 (1983). PRBMDO 0163-1829 10.1103/PhysRevB.27.7509

[55] G. Bimonte, T. Emig, R. L. Jaffe, and M. Kardar, Europhys. Lett. 97, 50001 (2012). EULEEJ 0295-5075 10.1209/0295-5075/97/50001

[56] G. Bimonte, T. Emig, and M. Kardar, Appl. Phys. Lett. 100, 074110 (2012). APPLAB 0003-6951 10.1063/1.3686903

[57] L. P. Teo, Phys. Rev. D 88, 045019 (2013). PRVDAQ 1550-7998 10.1103/PhysRevD.88.045019

[58] Edited by E. D. Palik, Handbook of Optical Constants of Solids (Academic Press, New York, 1985).

[59] Edited by E. D. Palik, Handbook of Optical Constants of Solids, Vol. 2 (Academic Press, New York, 1991).

[60] Edited by W. E. Beadle, J. C. C. Tsai, and R. D. Plummer, Quick Reference Manual for Silicon Integrated Circuit Technology (Wiley, New York, 1985).

[61] N. W. Ashcroft and N. D. Mermin, Solid State Physics (Saunders College, Philadelphia, 1976).

[62] D. B. Hough and L. R. White, Adv. Colloid Interface Sci. 14, 3 (1980). ACISB9 0001-8686 10.1016/0001-8686(80)80006-6

[63] L. Bergström, Adv. Colloid Interface Sci. 70, 125 (1997). ACISB9 0001-8686 10.1016/S0001-8686(97)00003-1

[64] S. G. Rabinovich, Measurement Errors and Uncertainties. Theory and Practice (Springer, New York, 2000).

[65] V. B. Svetovoy, P. J. van Zwol, G. Palasantzas, and J. Th. M. De Hosson, Phys. Rev. B 77, 035439 (2008). PRBMDO 1098-0121 10.1103/PhysRevB.77.035439

[66] P. J. van Zwol, G. Palasantzas, M. van de Schootbrugge, and J. Th. M. De Hosson, Appl. Phys. Lett. 92, 054101 (2008). APPLAB 0003-6951 10.1063/1.2832664

[67] R. O. Behunin, D. A. R. Dalvit, R. S. Decca, and C. C. Speake, Phys. Rev. D 89, 051301 (R) (2014). PRVDAQ 1550-7998 10.1103/PhysRevD.89.051301